4/29/05
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HFDM4 Test Summary

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1. Introduction

HFDM04 is a mirror magnet made from newly wound and cured Nb3Sn cable (see construction report) which was made of RRP 0.7 mm strand. The magnet was completed, installed into the VMTF dewar and electrically checked out by February 18th, 2005. The VMTF dewar was filled with liquid helium on February 22th, 2004. This magnet went trough only one test cycle. The cold test has been completed on February 25th. On March 11th, 2005 the magnet was at room temperature and on March 14th it was removed from the dewar.

2. Quench History and Quench Locations

The first quench of the magnet was at relatively low value (7042A). It was about ~60% of the critical current value calculated on the basis of short sample critical current measurements of strands. The magnet exhibited practically no training. The fifth quench was even much lower than the rest of the quenches. Then the magnet was cooled down to 2.2K to be exposed to higher Lorentz forces. Instead of increasing the quench current we observed quenches at ~5000 A current range. Increasing the temperature back to 4.5K the magnet quench current went back to the same current range we observed prior of quenching it at 2.2K. All the quench locations but one at 4.5K were at the inner coil mid-plane block. The 2.2K quenches were in the inner coil middle block region. Unfortunately it was not possible to further localize the quenches since there were not enough V-taps attached to the coils. Low quench current values and erratic behavior indicates that the magnet is likely to be limited by conductor instabilities. The quench summary is shown in Fig 1. and the details of quenches (and other quench or trip events) are described in Table 1.

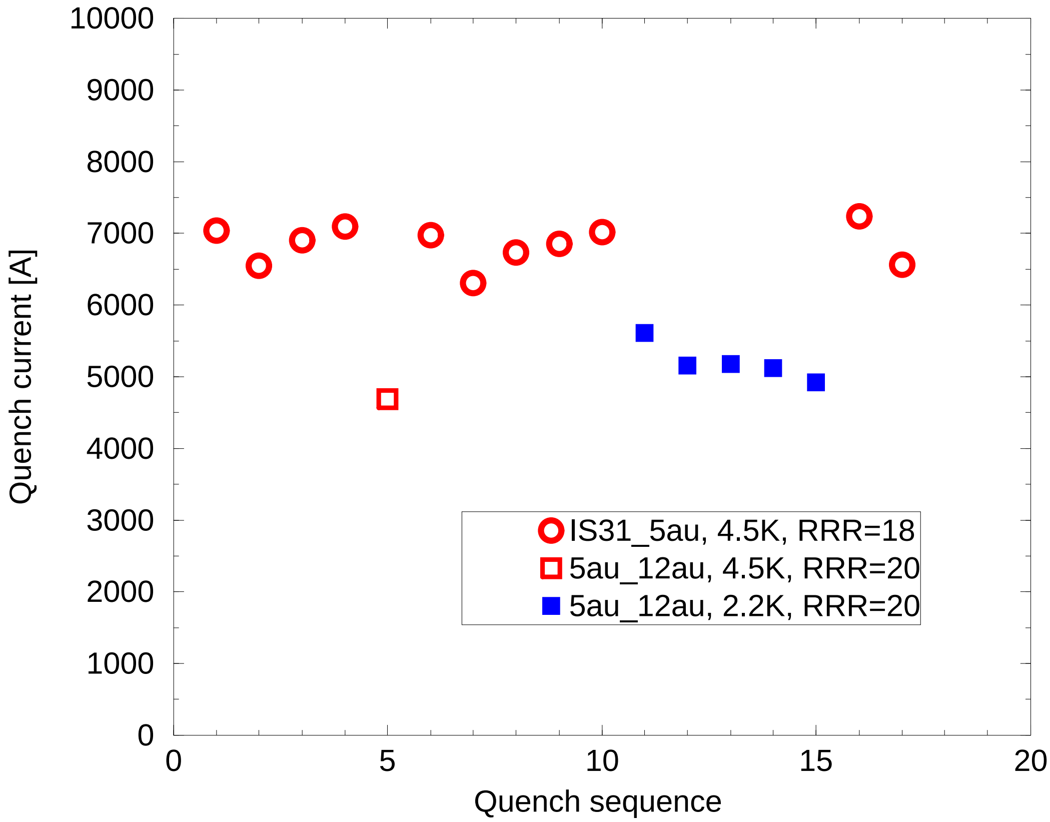


Fig. 1. Quench history of HFDM04 is shown.

File	Current	dI/dt	t_{quench}	MIITs	QDC	1st VTseg	t_{rise}	Mag Temp Bot L(1)	Voltage rises [V/s]	Comment
hfdm04.Quench.050222142158.127	191	99	-0.0141	0.04	WcoilGnd	QCC_QOS30	0.0160	4.4921		trip during balancing
hfdm04.Quench.050222142721.640	452	-9	-0.1817	0.08	WcoilGnd	Q12au_QCC	0.0238	4.4956		trip again
hfdm04.Quench.050222143514.397	121	-50	0.0073	0.04	HcoilHcoil	QIS31_Q5au	0.0168	4.4941		trip again
hfdm04.Quench.050222154157.750	6	0	-0.0015	0.04	GndRef	Q12au_QCC	0.0246	4.5098		trip again
hfdm04.Quench.050222154937.737	3	0	-0.5407	0.04	WcoilGnd	QCC_QOS30	0.0227	4.5098		trip again
hfdm04.Quench.050222155532.579	8	1	0.0106	0.04	GndRef	Q12au_QCC	0.0246	4.5101		trip again
hfdm04.Quench.050222162518.549	454	45	0.0161	0.05	WcoilIdot	Q5au_Q12au	0.0172	4.5093		trip after the AQD #3 was replaced
hfdm04.Quench.050222164616.088	459	41	0.0175	0.05	WcoilIdot	Q5au_Q12au	0.0249	4.5074		trip again
hfdm04.Quench.050222170835.039	1019	-1	0.0157	0.07	GndRef	QIS31_Q5au	0.0169	4.5084		1000A manual trip
hfdm04.Quench.050222173349.322	1017	0	0.0101	0.08	WcoilGnd	QCC_QOS30	0.0195	4.5052		1000A manual trip
hfdm04.Quench.050222175900.529	3027	0	0.0022	0.30	HcoilHcoil	Q12au_QCC	0.0098	4.5039		manual trip at 3000A since I was not able to change the heater voltage settings
hfdm04.Quench.050222180715.868	3024	-1	-0.0319	0.60	HcoilHcoil	Q12au_QCC	0.0098	4.5025		3000A heater induced quench, 4.5K
hfdm04.Quench.050222181818.233	3427	45	0.0150	0.21	HcoilHcoil	QCC_QOS30	0.0101	4.5012		trip at low current
hfdm04.Quench.050222183129.344	**7042**	20	-0.0013	1.31	HcoilHcoil	QIS31_Q5au	-0.0013	4.5020	21.9±0.5	7042A trip or quench at 4.5K, 20A/s, 1st quench
hfdm04.Quench.050222184351.493	3234	20	-0.0022	0.37	HcoilHcoil	QIS31_Q5au	0.0087	4.5042		~3200A was trip
hfdm04.Quench.050222190006.000	3354	20	-0.0015	0.39	HcoilHcoil	Q12au_QCC	0.0097	4.5010		another trip
hfdm04.Quench.050222191536.326	**6550**	20	-0.0055	1.33	HcoilHcoil	QIS31_Q5au	-0.0048	4.4998	11.5±0.4	6550A, 20A/sec, 4.5K, 2nd quench
hfdm04.Quench.050222193240.457	**6904**	20	-0.0017	1.27	HcoilHcoil	QIS31_Q5au	-0.0011	4.5006	85.3±1.6	3rd quench, Iq=6904A, 20A/sec, 4.5K
hfdm04.Quench.050223113502.882	19	0	1.0000	0.00	GndRef	0	0.0000			
hfdm04.Quench.050223152107.631	1014	0	0.0011	0.09	WcoilIdot	QIS31_Q5au	0.0070	4.5277		Ramped to 1000A, trip manually on DQD_Coil to test phaseback delay qlm has been checked out as OK, but RN found a transistor not soldered within the PS Interface module...
hfdm04.Quench.050223153222.770	1016	0	0.0003	0.09	HcoilHcoil	QIS31_Q5au	0.0150	4.5183		another manual trip at 1000A to check phaseback signal at the ps interface box.
hfdm04.Quench.050223171611.867	**7097**	20	-0.0161	2.08	HcoilHcoil	QIS31_Q5au	-0.0153	4.5112	18.1±0.3	4th quench, Iq=7097A, 20A/s, 4.5K
hfdm04.Quench.050223172937.698	**4690**	20	-0.0372	1.47	WcoilIdot	Q5au_Q12au	-0.0097	4.5148	4.8±0.2	5th quench, Iq=4690A, 20A/s, 4.5K

hfdm04.Quench.050224100039.930	1014	0	0.0011	0.08	WcoilIdot	QIS31_Q5au	0.0018	4.5043		manual dqd_coil trip at 1000A to test ps #1 with spare PSIM installed
hfdm04.Quench.050224151851.315	1016	0	-0.0045	0.08	GndRef	QIS31_Q5au	0.0014	4.5132		1000A manual trip to check ps phaseback
hfdm04.Quench.050224153914.217	1020	0	-0.0084	0.10	GndRef	QIS31_Q5au	0.0027	4.5019		manual trip at 1000A, 25ms dump delay, testing phaseback
hfdm04.Quench.050224154545.561	1016	0	0.0018	0.09	WcoilIdot	QCC_QOS30	0.0031	4.5005		repeat of 1000A manual trip to capture phaseback signals. dump delay of 25ms.
hfdm04.Quench.050224160812.891	1013	0	0.0004	0.09	HcoilHcoil	QCC_QOS30	0.0161	4.5007		final 1000A manual trip to test phaseback. pei's 1,3,4 operating, dump delayed 25ms, heater1 no delay 350V
hfdm04.Quench.050224163055.051	1020	0	0.0003	0.09	HcoilHcoil	Q12au_QCC	0.0248	4.4986		1000A manual trip with PLC qlm phaseback output forced off.
hfdm04.Quench.050224163920.223	1020	0	0.0003	0.09	HcoilHcoil	Q5au_Q12au	0.0248	4.5008		second test repeat with plc qlm output forced off
hfdm04.Quench.050224164810.772	1014	0	0.0014	0.09	WcoilIdot	QIS31_Q5au	0.0021	4.5014		another test, qlm INPUT to PLC is FORCED OFF. checking phaseback
hfdm04.Quench.050224170837.710	1018	0	0.0003	0.09	HcoilHcoil	QIS31_Q5au	0.0232	4.5010		1000A manual trip new QLM
hfdm04.Quench.050224171716.440	1006	0	0.0003	0.09	HcoilHcoil	QIS31_Q5au	0.0179	4.5010		1000A manual trip with 1 PS on
hfdm04.Quench.050224172916.740	7	0	0.0113	0.04	SlWcoil	Q12au_QCC	0.0248	4.4990		heater delay check
hfdm04.Quench.050224174641.086	1012	0	0.0010	0.09	GndRef	QIS31_Q5au	0.0003	4.4980		1000A mnual trip with stand 4 QLM
hfdm04.Quench.050224175051.698	1012	0	0.0013	0.09	WcoilIdot	QIS31_Q5au	0.0011	4.4967		1000A manual trip with stand 4 QLM
hfdm04.Quench.050224181938.200	1012	0	0.0008	0.09	GndRef	QIS31_Q5au	0.0008	4.4951		1000A manual trip
hfdm04.Quench.050224182401.005	1008	0	0.0011	0.08	WcoilIdot	QIS31_Q5au	0.0014	4.4951		1000A manual trip
hfdm04.Quench.050224183455.641	1008	0	0.0014	0.08	WcoilIdot	QIS31_Q5au	0.0025	4.4966		original QLM is back, 1000A manula trip
hfdm04.Quench.050224184641.128	**6876**	20	-0.0168	2.59	HcoilHcoil	QIS31_Q5au	-0.0158	4.4966	16.3±0.3	6th quench, Iq=6876A, 20A/s, 4.5K
hfdm04.Quench.050225075152.213	**6304**	20	-0.0400	3.15	HcoilHcoil	QIS31_Q5au	-0.0188	4.4511	12.3±0.2	7th quench, 20A/s, 4.5K, Iq=6304A
hfdm04.Quench.050225081715.719	**6857**	0	-0.5708	27.69	WcoilGnd	QIS31_Q5au	-0.0076	4.4740	63.9±2.0	8th quench, Iq=6732A, 20a/sec, 4.5K
hfdm04.Quench.050225083113.911	**6857**	0	-0.5256	26.59	HcoilHcoil	QIS31_Q5au	-0.0062	4.4859	65.4±1.6	9th quench, 20A/sec, Iq=6857A, 4.5K
hfdm04.Quench.050225084612.233	**7019**	20	-0.0105	2.37	WcoilIdot	QIS31_Q5au	-0.0094	4.4915	28.5±0.6	10th quench, Iq=7019A, 20A/s, 4.5K
hfdm04.Quench.050225131921.605	513	0	0.0008	0.04	GndRef	QIS31_Q5au	0.0021	2.1662		500A manual tripCoef
hfdm04.Quench.050225132743.016	509	0	0.0001	0.05	HcoilHcoil	QIS31_Q5au	0.0035	2.1633		500A manual trip to check the ground fault circuit
hfdm04.Quench.050225133511.750	**5609**	20	-0.0230	2.03	HcoilHcoil	QIS31_Q5au	0.0006	2.1631	12.3±0.3	11th quench, Iq=5609A, 2.2K, 20A/s
hfdm04.Quench.050225134834.930	**5153**	20	-0.0333	2.02	WcoilGnd	QIS31_Q5au	0.0013	2.1630	8.1±0.2	12th quench, Iq=5153A, 20a/s, 2.2K

hfdm04.Quench.050225140720.161	**5179**	20	-0.0333	2.03	WcoilGnd	QIS31_Q5au	0.0008	2.1629	6.7±0.2	13th quench, Iq=5179A, 2.2K, 20A/s
hfdm04.Quench.050225142626.993	**5121**	20	-0.0360	2.07	HcoilHcoil	QIS31_Q5au	-0.0001	2.1638	8.8±0.2	14th quench, Iq=5121A, 2.2K, 20A/s
hfdm04.Quench.050225143850.411	**4922**	20	-0.0322	1.83	WcoilIdot	QOS30_QOS31	0.0010	2.1631	6.8±0.2	15th quench, Iq=4922A, 20A/sec, 2.2K
hfdm04.Quench.050225152423.591	14	0	0.0160	0.00	WcoilGnd	Q12au_QCC	1.0000	4.0959		Manual trip using fpga qlm (tests)
hfdm04.Quench.050225164011.569	-29	0	0.0001	0.04	SlWcoil	Q12au_QCC	0.0000	4.4948		
hfdm04.Quench.050225164436.868	155	0	-0.0001	0.04	SlWcoil	Q12au_QCC	-0.0003	4.4961		manual trip of using fpga qlm for test @100Amps
hfdm04.Quench.050225171416.546	**3026**	0	-0.0617	0.78	HcoilHcoil	QOS30_QOS31	-0.0112	4.5110		Heater induced quench @3000Amps to test FPGA QLM
hfdm04.Quench.050225173200.686	24	0	-0.0249	0.04	HcoilHcoil	Q12au_QCC	-0.0003	4.5106		trip to check the dump delay
hfdm04.Quench.050225174442.414	**7239**	20	-0.0056	2.17	HcoilHcoil	QIS31_Q5au	-0.0049	4.5120	31.2±1.5	16th quench, Iq=7239A, 20A/sec, 4.5K
hfdm04.Quench.050225175633.730	**6561**	20	-0.0328	2.11	HcoilHcoil	QIS31_Q5au	-0.0322	4.5188	34.5±1.0	17th quench, Iq=6561A, 20A/sec, 4.5K
hfdm04.Quench.050302120508.895										
hfdm04.Quench.050302160116.020										
hfdm04.Quench.050309150422.170	16	0	0.0008	0.00	WcoilIdot	Q12au_QCC	1.0000	287.5229		

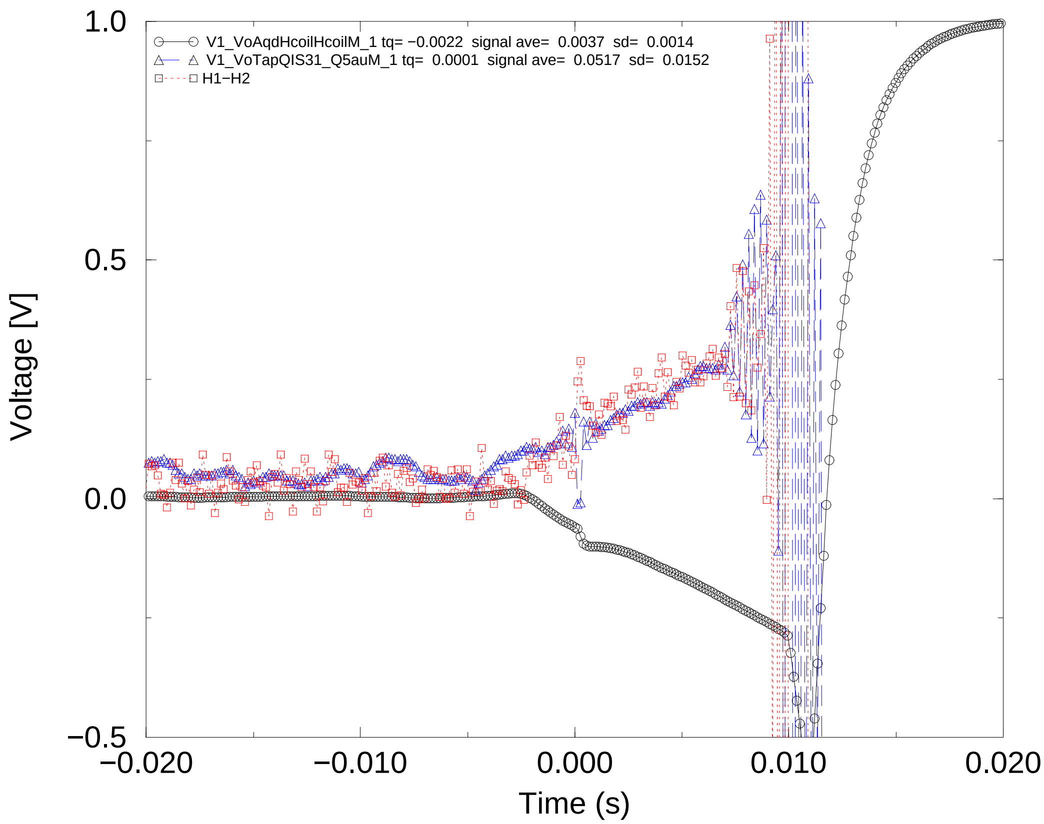


Fig 2. Voltage traces for quench number 1. Three voltage segments are plotted: two half coil bucked signals and QIS31_Q5au where the quench has started.

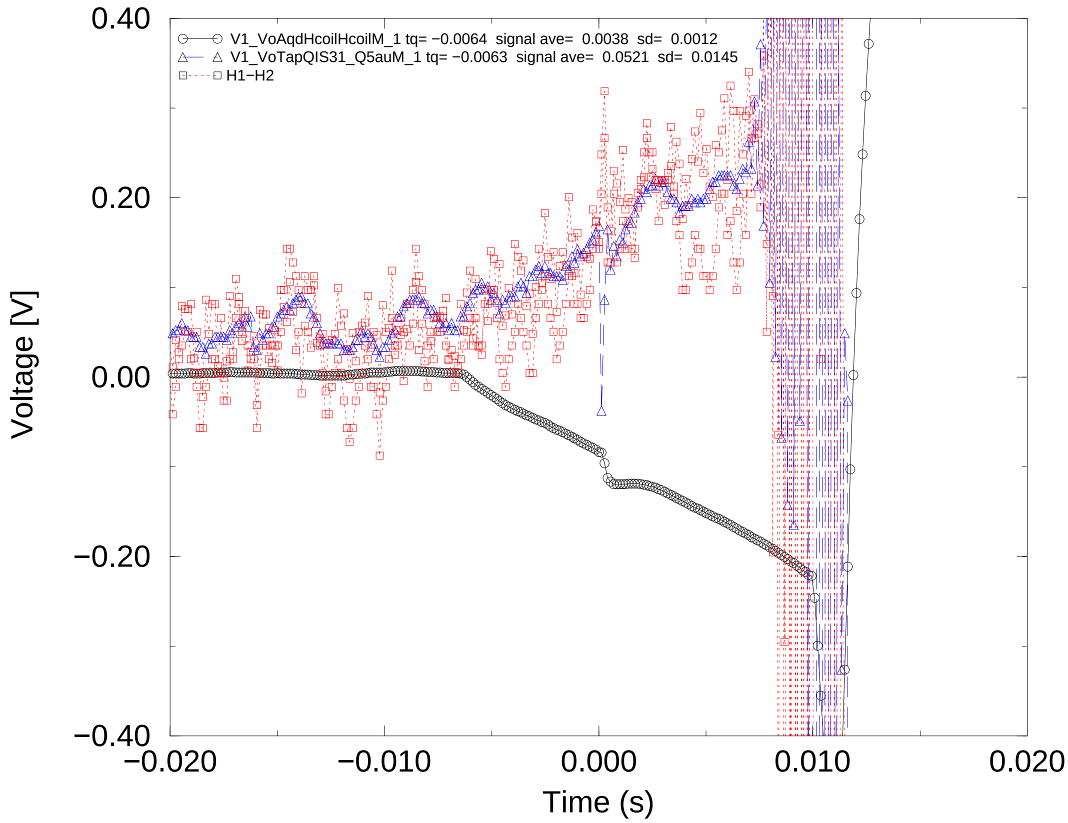


Fig 3. Voltage traces for quench number 2. Three voltage segments are plotted: two half coil bucked signals and QIS31_Q5au where the quench has started.

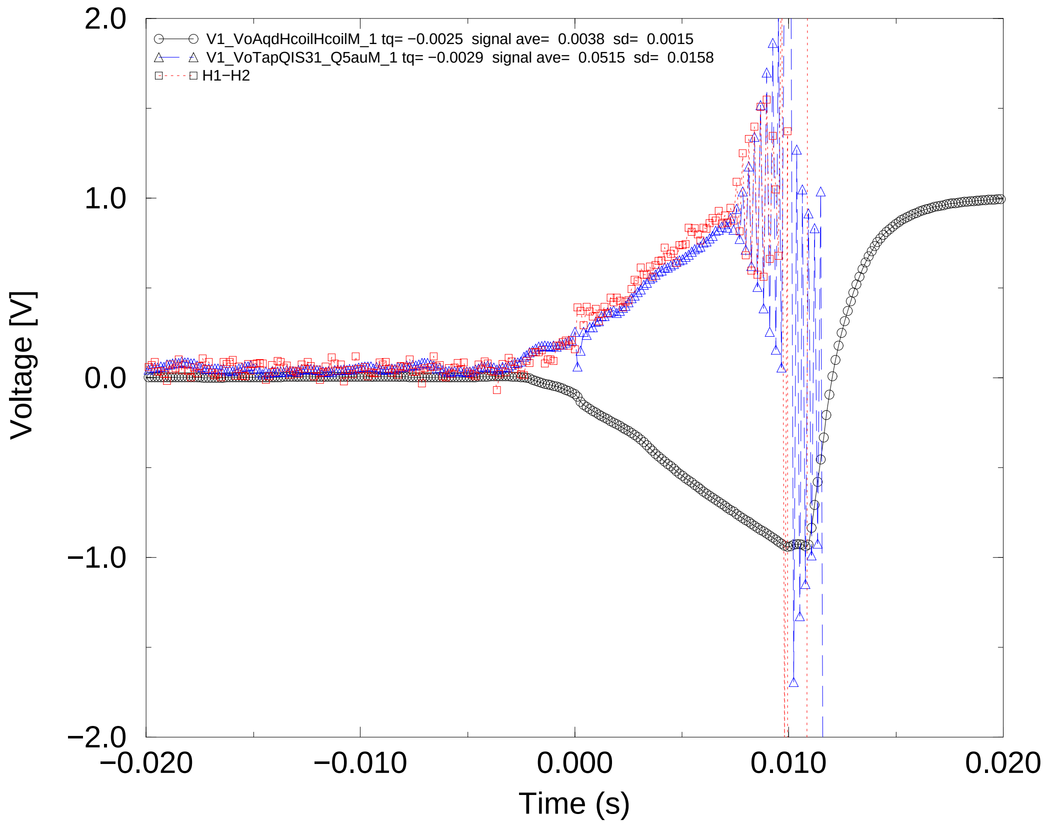


Fig 4. Voltage traces for quench number 3. Three voltage segments are plotted: two half coil bucked signals and QIS31_Q5au where the quench has started.

From Fig.2 to Fig. 4. one can notice that the voltage rises of the first and the second quenches relative to the third one are quite different. We analyzed each quenches and determined the rate of the resistance rise for the first few milliseconds. The resistance rise can be converted to quench propagation velocity by making the assumption that the cable resistance (1.7 mΩ/m) and the RRR (20) is known. Since the average field is 2-3 T the magneto-resistance was neglected. The obtained quench velocity as a function of the magnet current is plotted in Fig. 5. Some of the voltage rises were quite high so we obtained unrealistic quench velocities. However, if we make the assumption that these quenches occurred simultaneously at multiple locations we have to divide the quench velocities with the number of locations. The newly obtained (normalized to one turn or location) quench velocities fall into the expected range of velocities as a function of the quench current. We can also conclude that the relatively low quench velocity value (< 20 m/s) is consistent with a quench current being far from the critical current limit.

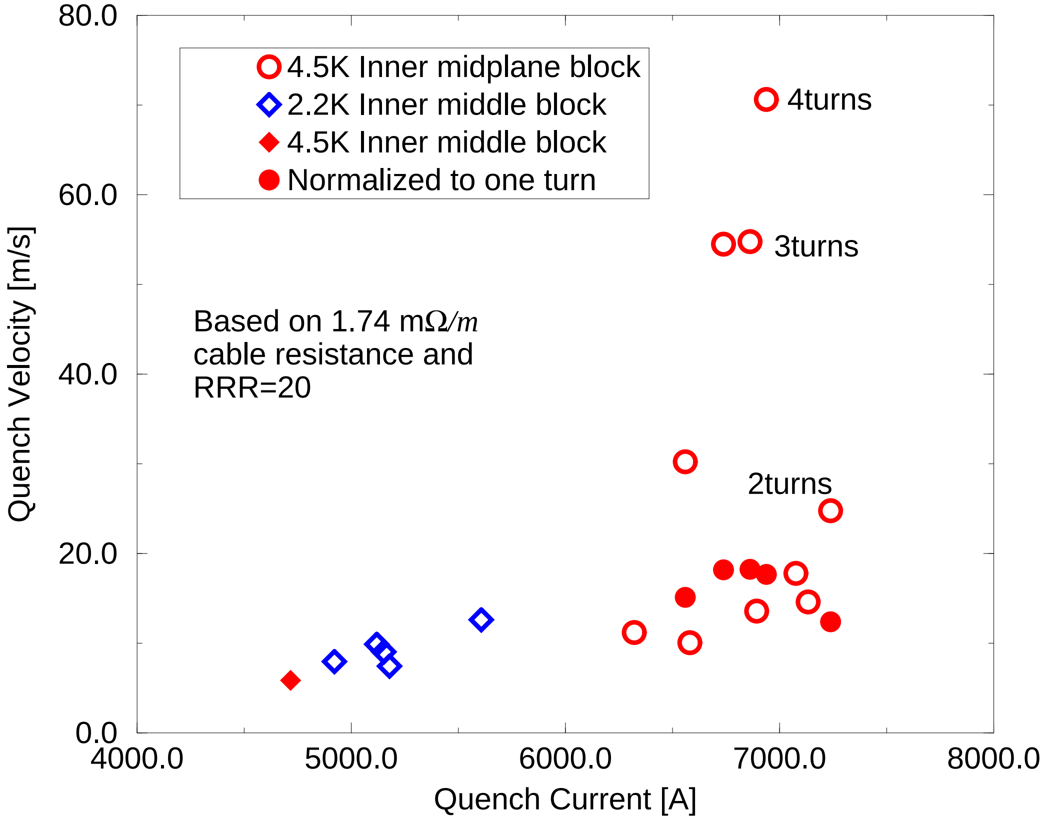


Fig 5. Quench velocities as a function of quench current. Some of the quench velocities were unrealistically high probably due to the fact that we were estimating them by resistance rise and there were multiple quenches at the same block we recorded the voltage. Dividing the quench velocity values with an appropriate integer number (number of locations or turns) the newly obtained normalized values fall within the expected range.

In Fig. 6. quench #11 was plotted. It is quite clear from the voltage rise and from the calculated quench velocities of the two different phase of the propagation that about -3ms prior the quench was detected the quench propagation speeds up. It is consistent with a hypothesis that all the seven turns of the inner coil middle block have quenched caused a faster voltage rise.

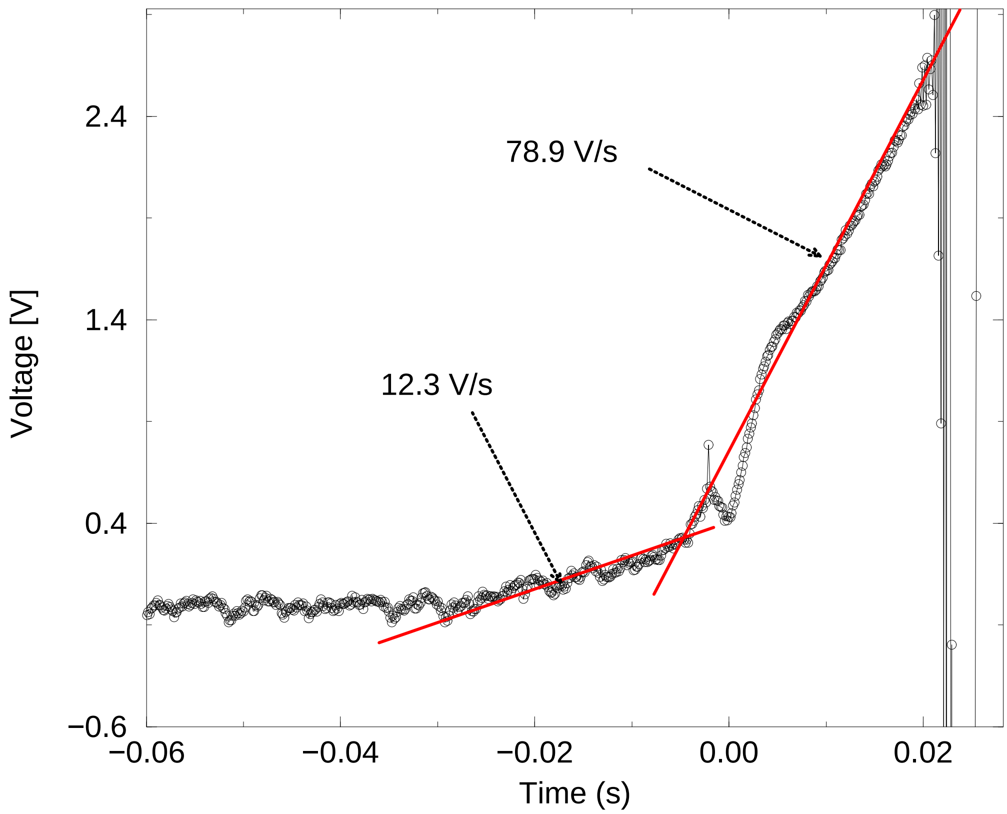


Fig. 6. Voltage rise of the 11th quench is plotted. Multiple turn quench was observed at -3ms time stamp.

3. Strain gauge results

This magnet was instrumented with several strain gauges. The summary of the gauges are summarized in Table 2. The warm measurement results of these strain gauges are presented in the production summary report.

Table 2. Strain gauge naming and locations.

HFDM04 Instrumentation Summary

Strain Gauges (resistive) on Spacers

Label	Type	Location
SPARG27	Active	RE top (coil pole)
SPARG28	Active	RE midplane right
SPCRG14	Temp Comp	RE midplane left
SPARG23	Active	LE top (coil pole)
SPARG24	Active	LE (splice) midplane right
SPCRG12	Temp Comp	LE midplane left

Note: "Left" and "Right" refer to magnet as viewed from the lead end looking toward non-lead end.

Strain Gauges (resistive) on skin

Label	Type	Location
SKUARG-30	Active	Upper skin
SKUARG-60	Active	Upper skin
SKUARG-90	Active	Upper skin
SKUCRG-60	Temp Comp	Upper skin
SKLARG-30	Active	Lower skin
SKLARG-60	Active	Lower skin
SKLARG-90	Active	Lower skin
SKLCRG-60	Temp Comp	Lower skin

Strain Gauges (resistive) on coil IR between wedges

Label	Type	Location
1a	Active	on coil RE
1c	Temp Comp	on coil RE
2a	Active	on coil RE
2c	Temp Comp	on coil RE
3a	Active	on coil SS
3c	Temp Comp	on coil SS
4a	Active	on coil SS
4c	Temp Comp	on coil SS

Beam Gauges

Label	Type	Location
64InLE	Active	LE (splice) midplane inner
62InSS	Active	SS midplane inner layer
67outSS	Active	SS midplane outer layer
63outLE	Active	LE (splice) midplane outer
61InSS	Active	SS midplane inner layer
65OutSS	Active	SS midplane outer layer

Only gauges which were mounted directly onto the inner surface of the coil and the beam gauges located in the body part of the magnet showed change under Lorentz forces. Individual strain gauge results are summarized in Fig. 6 – Fig. 25. All the plots correspond to current ramps at 4K helium bath temperature.

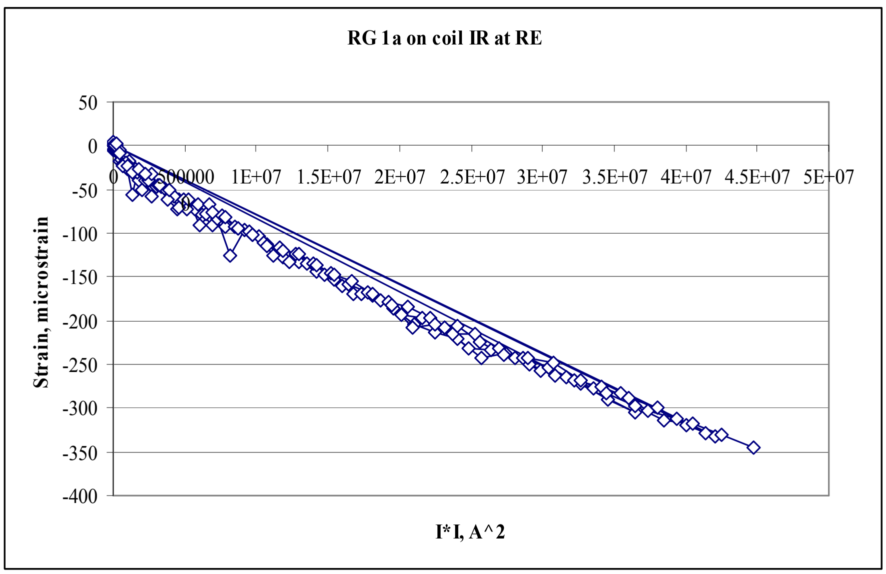


Fig. 7. Resistive gauge mounted inside coil surface showed clear strain dependence as a function of the Lorentz force.

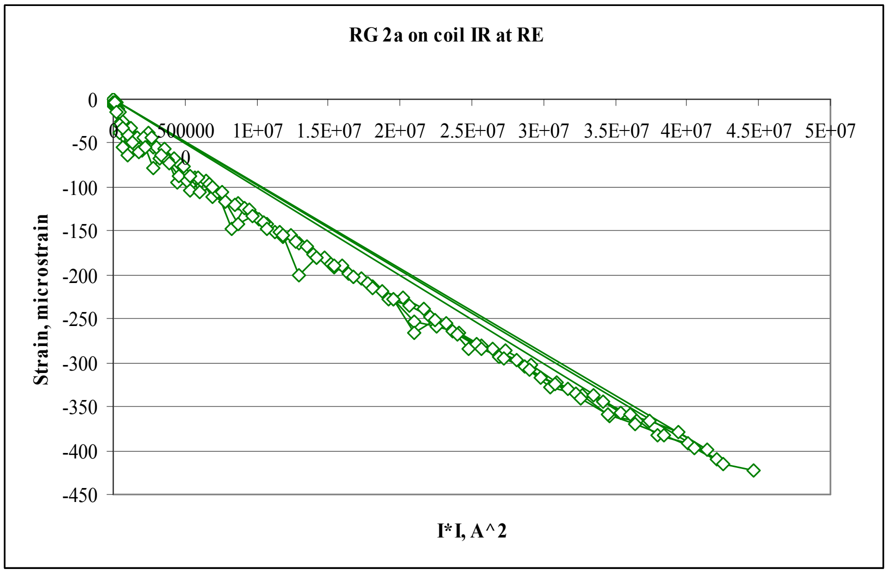


Fig. 8. Resistive gauge mounted inside coil surface showed clear strain dependence as a function of the Lorentz force.

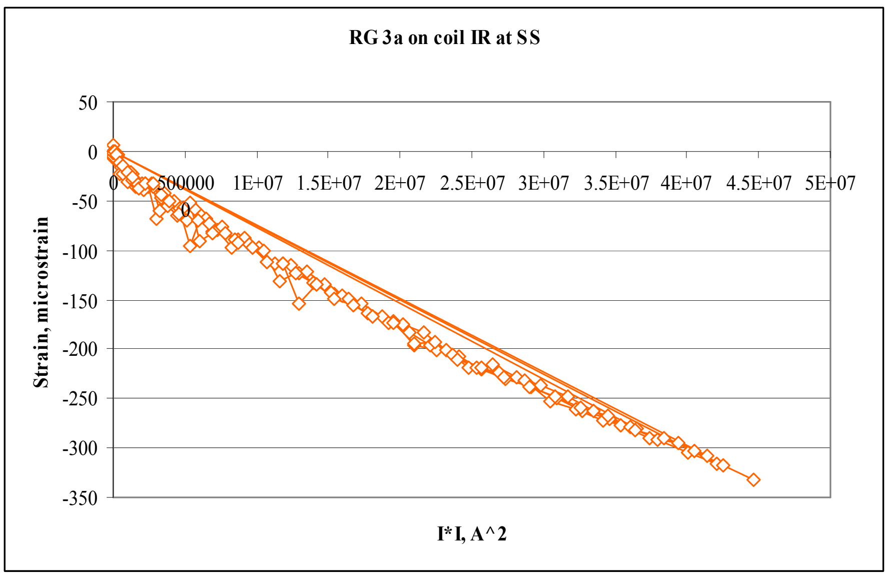


Fig. 9. Resistive gauge mounted inside coil surface showed clear strain dependence as a function of the Lorentz force.

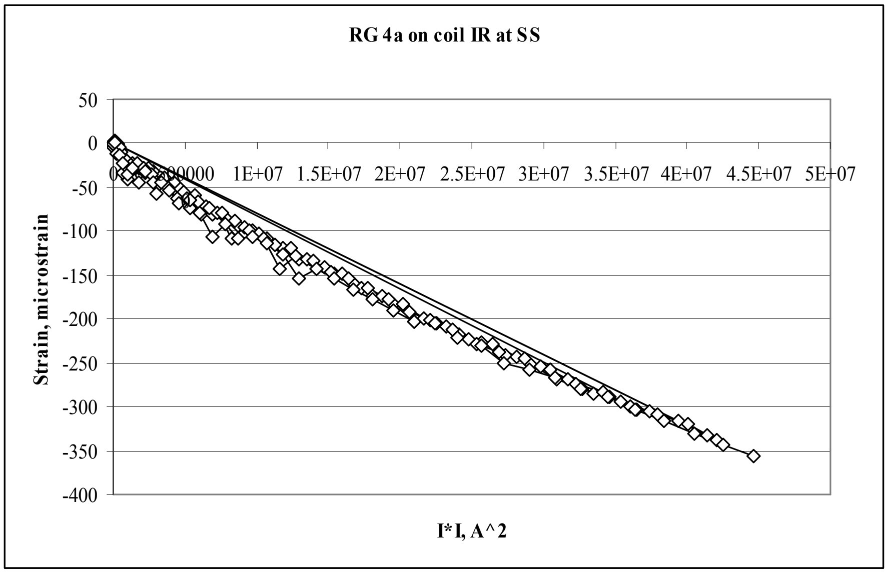


Fig. 10. Resistive gauge mounted inside coil surface showed clear strain dependence as a function of the Lorentz force.

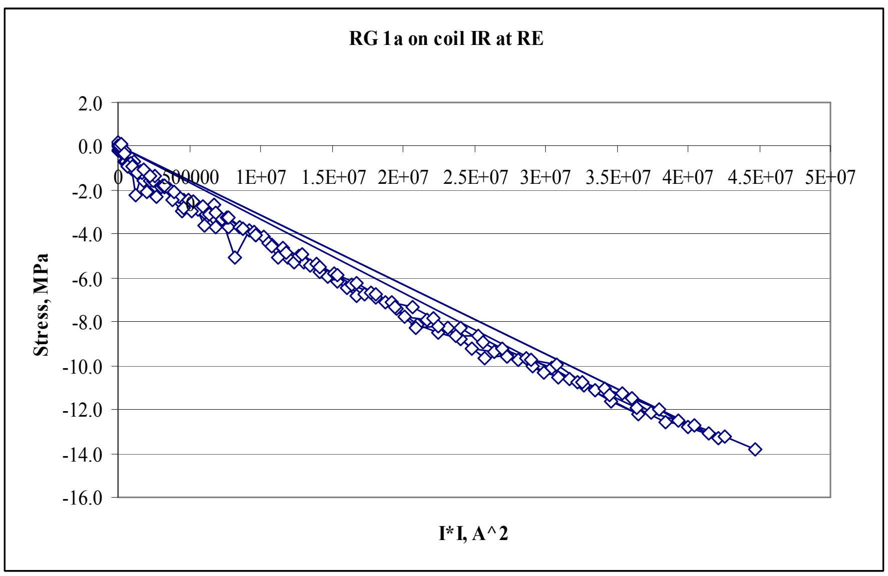


Fig. 11. Resistive gauge mounted inside coil surface showed clear stress dependence as a function of the Lorentz force.

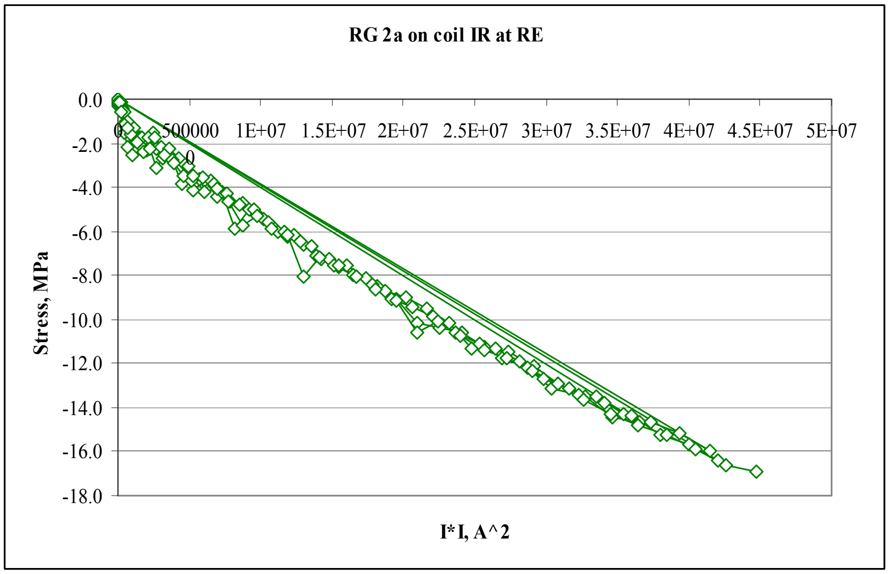


Fig. 12. Resistive gauge mounted inside coil surface showed clear stress dependence as a function of the Lorentz force.

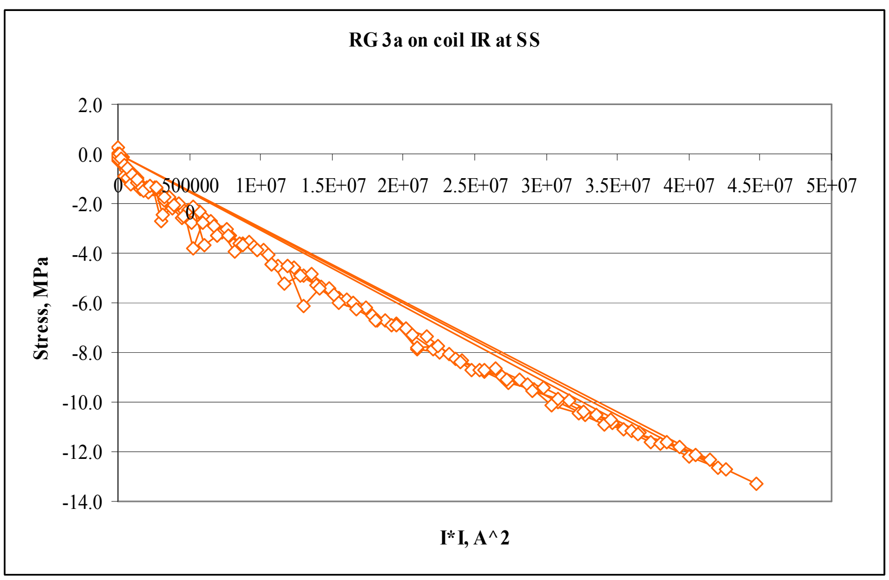


Fig. 13. Resistive gauge mounted inside coil surface showed clear stress dependence as a function of the Lorentz force.

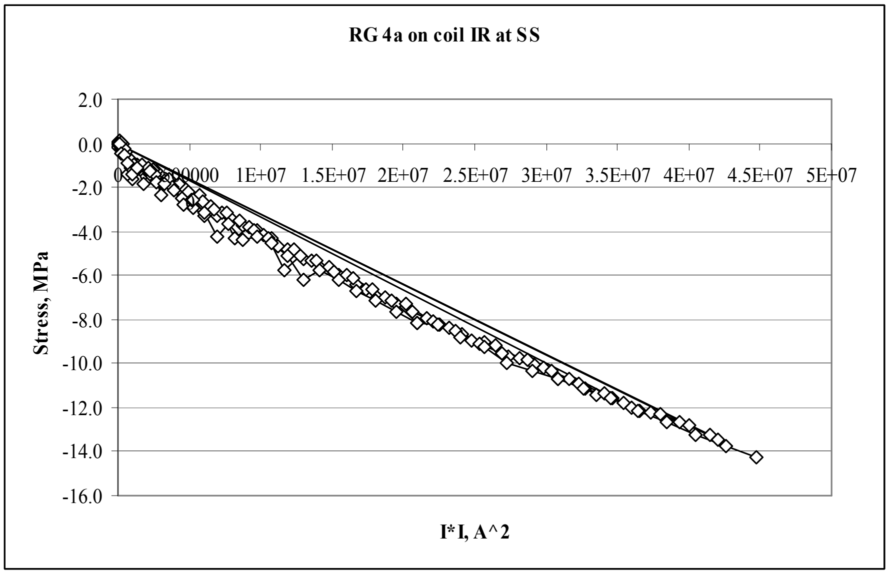


Fig. 14. Resistive gauge mounted inside coil surface showed clear stress dependence as a function of the Lorentz force.

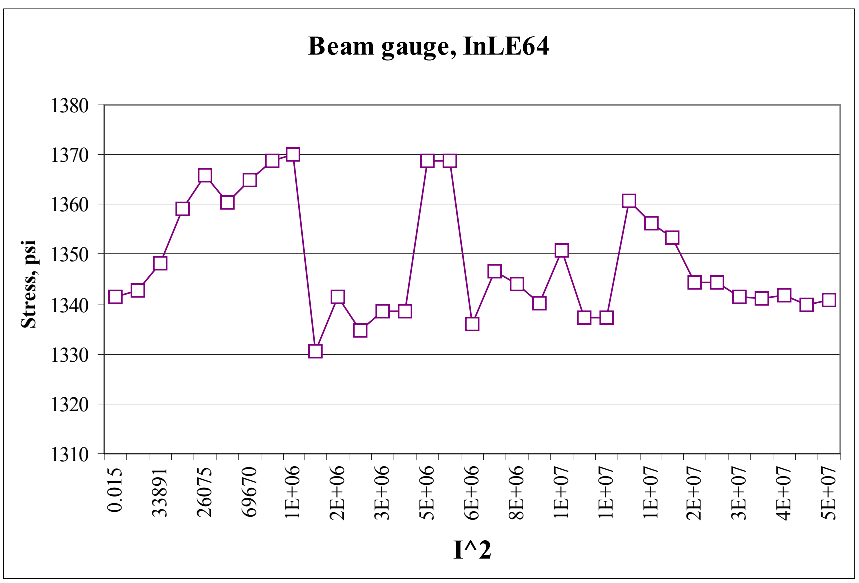


Fig. 15. Resistive beam gauge mounted at the surface of the mid-plane close to the splice region showed no clear sign of loading.

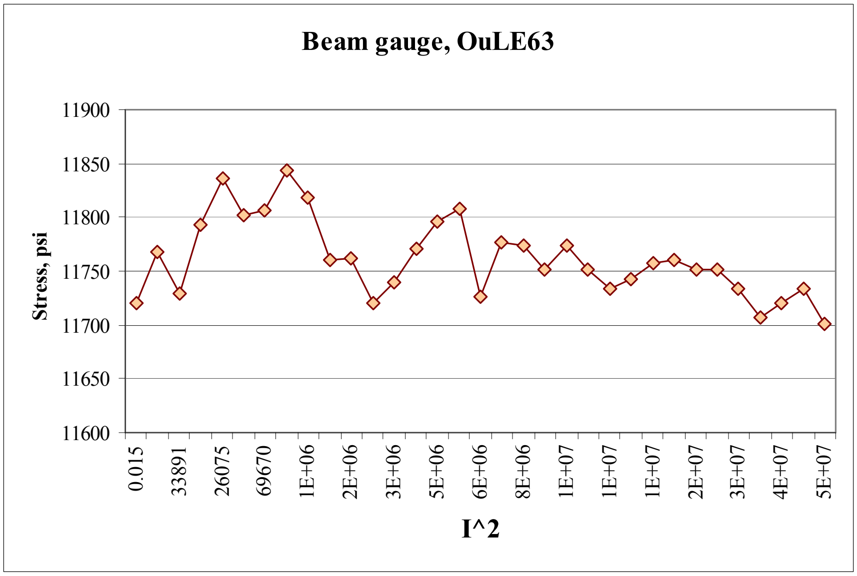


Fig. 16. Resistive beam gauge mounted at the surface of the mid-plane close to the splice region showed no clear sign of loading.

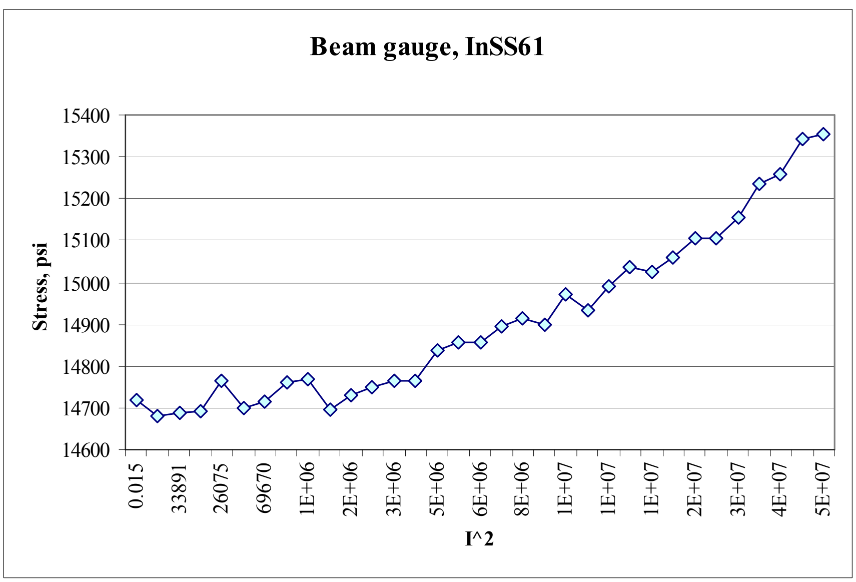


Fig. 17. Resistive beam gauge mounted at the surface of the mid-plane in the body region of the coil showed a clear change of the load as a function of the Lorentz force.

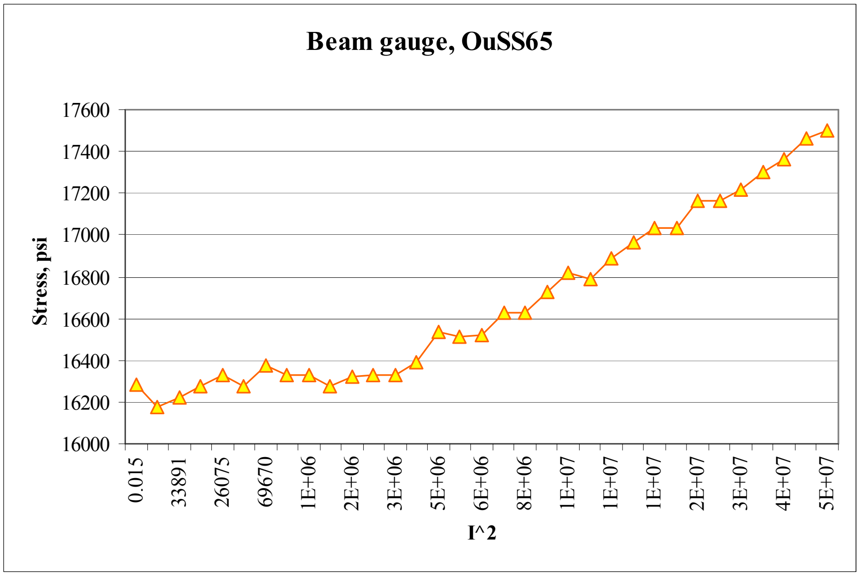


Fig. 18. Resistive beam gauge mounted at the surface of the mid-plane in the body region of the coil showed a clear change of the load as a function of the Lorentz force.

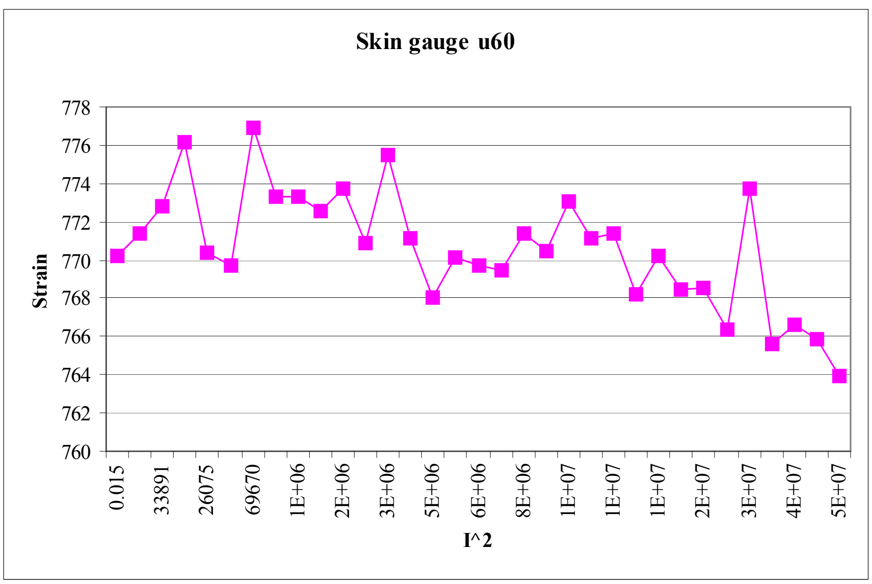


Fig. 19. Resistive skin gauge showed no clear change of the load as a function of the Lorentz force.

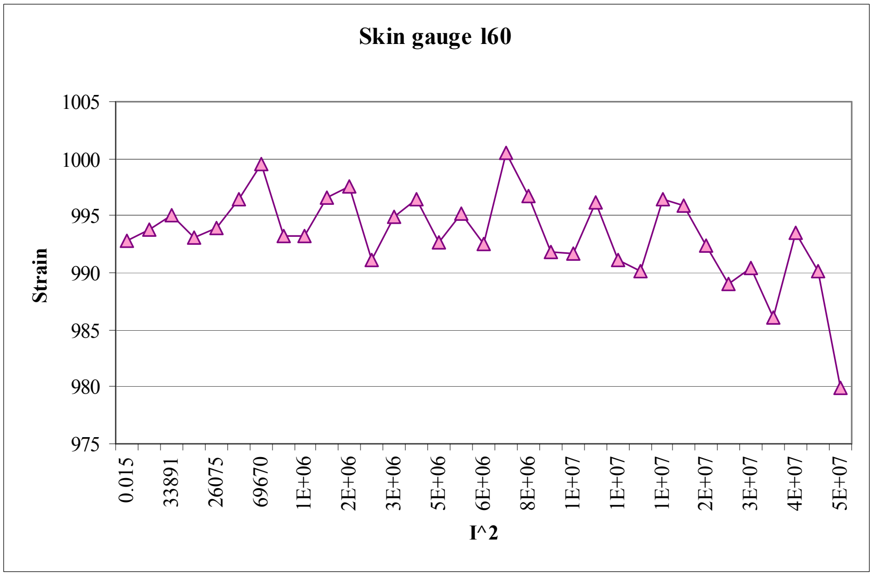


Fig. 20. Resistive skin gauge showed no clear change of the load as a function of the Lorentz force.

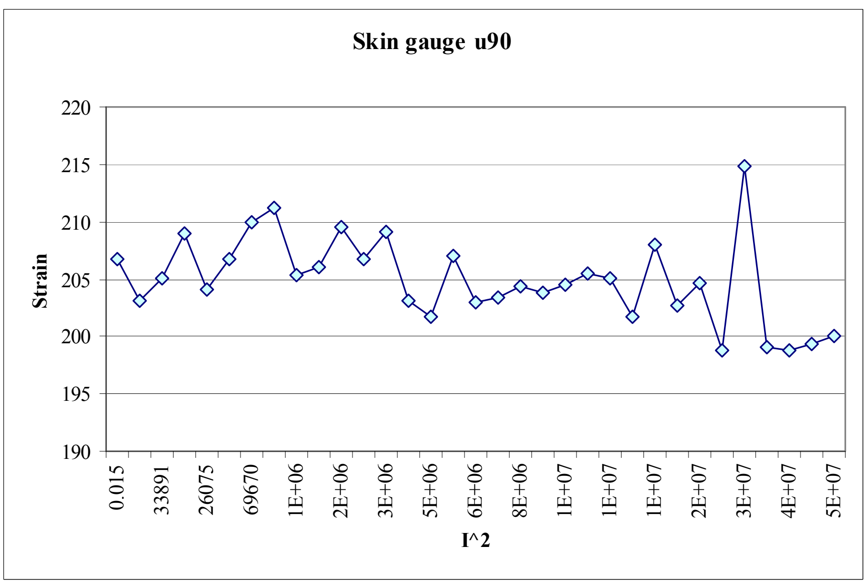


Fig. 21. Resistive skin gauge showed no clear change of the load as a function of the Lorentz force.

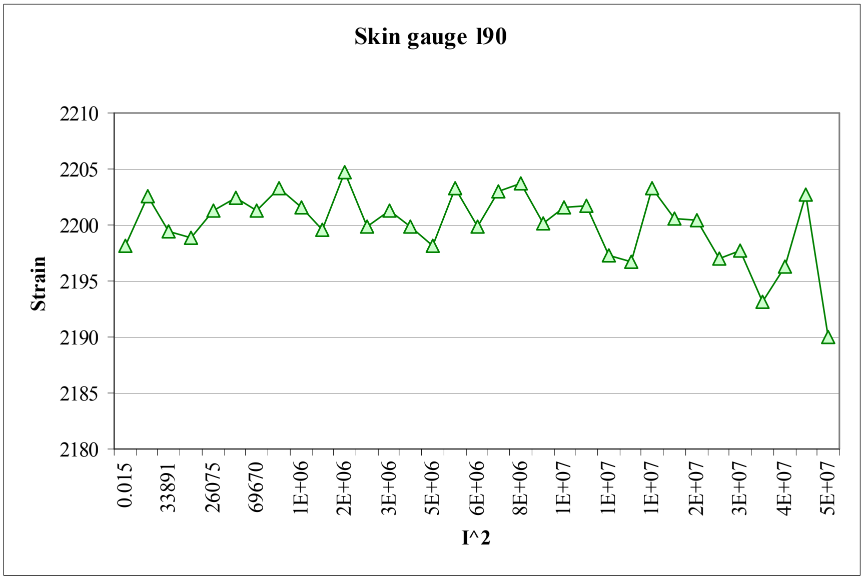


Fig. 22. Resistive skin gauge showed no clear change of the load as a function of the Lorentz force.

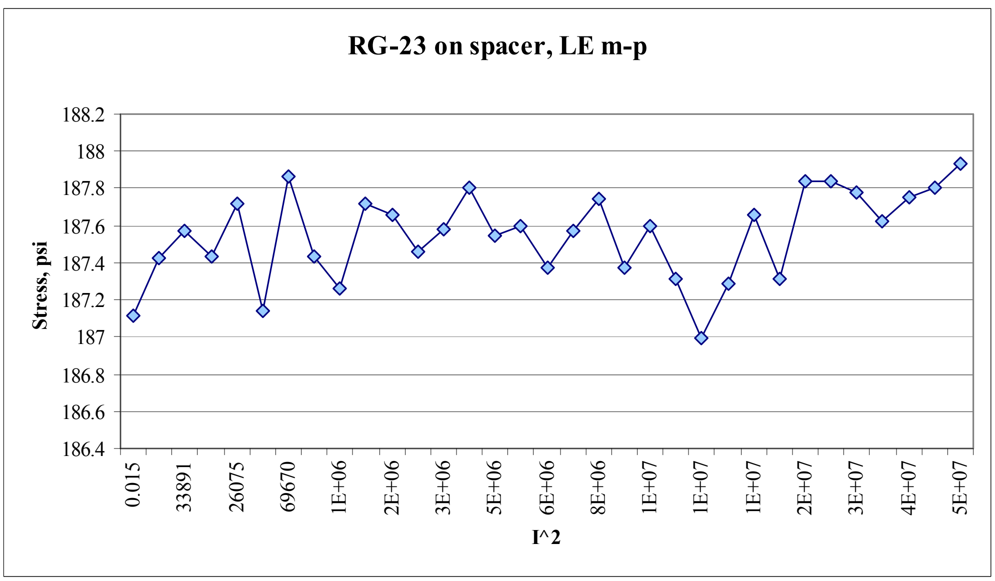


Fig. 23. Resistive gauge mounted onto the surface of the spacer showed no clear change of the load as a function of the Lorentz force.

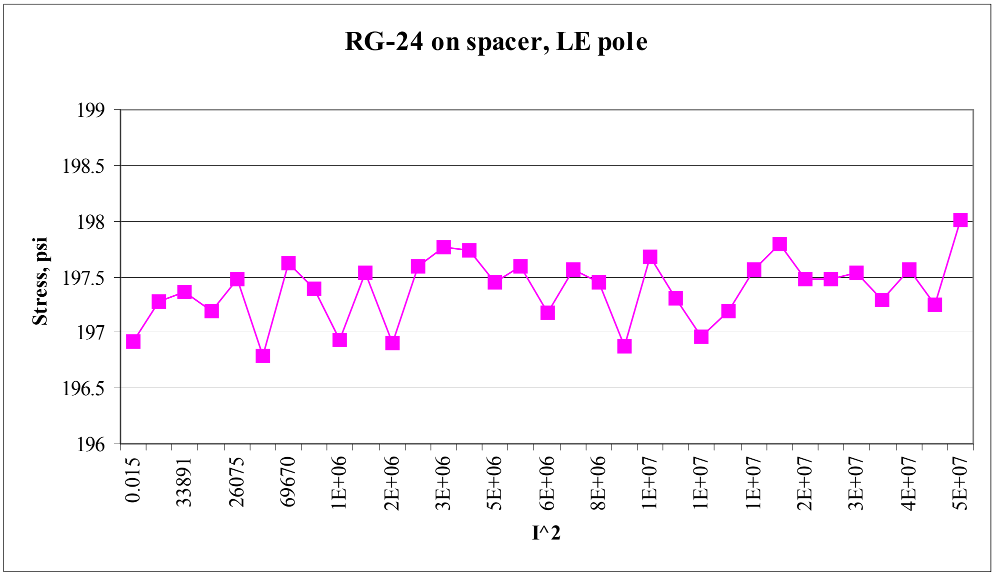


Fig. 24. Resistive gauge mounted onto the surface of the spacer showed no clear change of the load as a function of the Lorentz force.

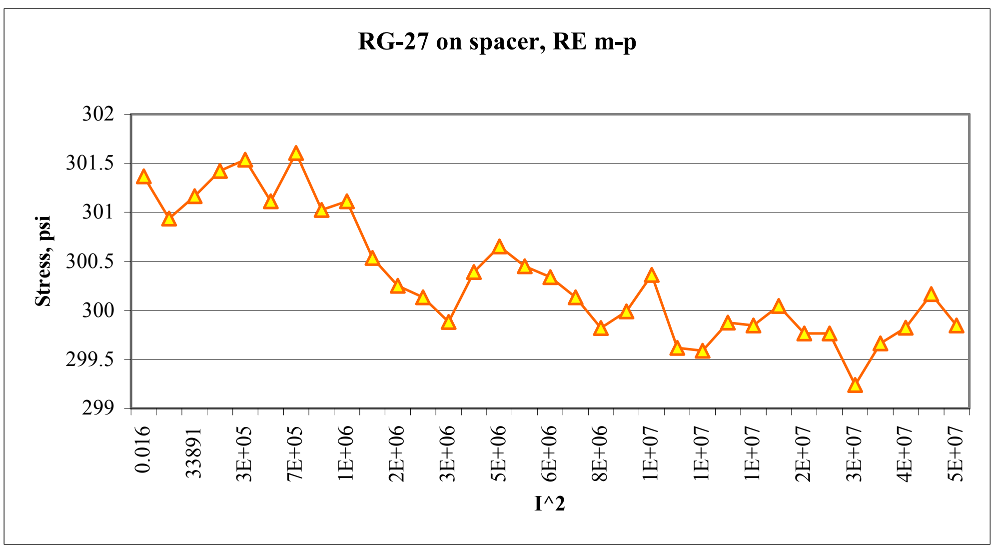


Fig. 25. Resistive gauge mounted onto the surface of the spacer showed no clear change of the load as a function of the Lorentz force.

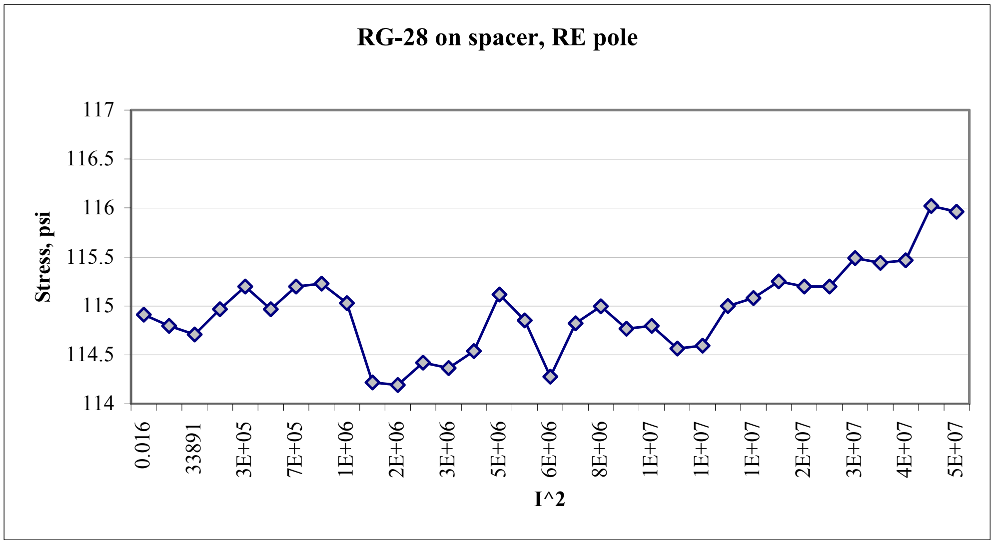


Fig. 26. Resistive gauge mounted onto the surface of the spacer showed no clear change of the load as a function of the Lorentz force.

4. RRR measurements

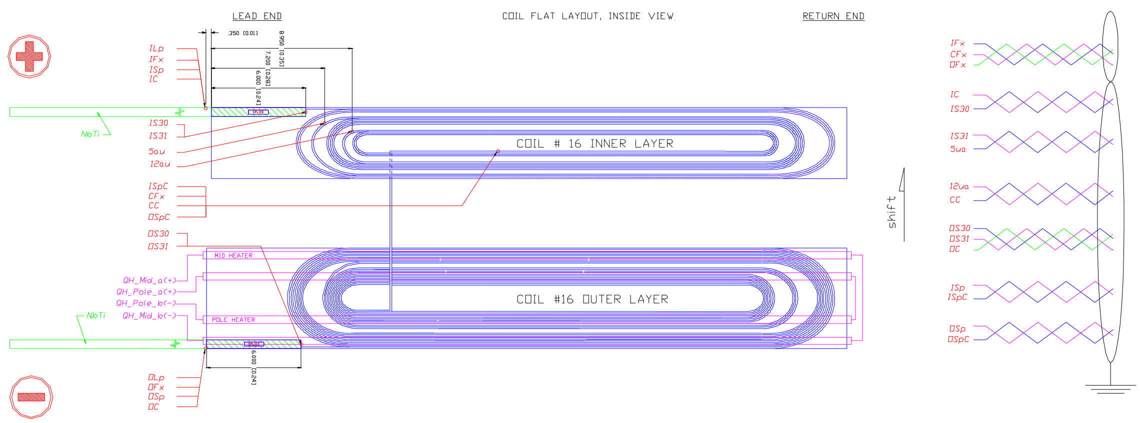
After the cold test was completed the magnet was gradually warmed up. We used this opportunity to measure the magnet voltages under small current (± 10A) values as a function of the magnet temperature. The obtained RRR value is 18 for the inner coil and 20 for the outer coil.

5. Voltage Spike Studies

During the test many voltage spikes were detected. Due to the high level of electronic noise and the difficulties to balance uneven voltage segments (the two halves were not equal since outer and inner coil segments were compared with each other) the data was not taken with the same conditions through the test. Without being completely quantitative the following observations can be made:

1. Most of the voltage spike signals had the same characteristic shape: fast rising edge and a slow falling tail. It looks like each signal is made of lot of small signals simply added together.
2. No special unusual "slip-stick" characteristic signal (high frequency oscillation with damping) was observed.
3. Every current range we were able to observe voltage spikes.
4. Almost every quench recorded have sharp start of their voltage signal which might be related to voltage spikes which occurred right before the quench was initiated.

6. Appendix



LEAD END
COIL FLAT LAYOUT, INSIDE VIEW
RETURN END
.350 [0.01]
8.950 [0.35]
7.200 [0.28]
6.000 [0.24]
ILp
IFx
ISp
IC
IS30
IS31
5au
12au
NbTi
COIL # 16 INNER LAYER
ISpC
CFx
CC
OSpC
OS30
OS31
MID HEATER
QH_Mid_a(+)
QH_Pole_a(+)
QH_Pole_b(-)
QH_Mid_b(-)
NbTi
POLE HEATER
COIL #16 OUTER LAYER
6.000 [0.24]
OLp
OFx
OSp
OC
shift
IFx
CFx
OFx
IC
IS30
IS31
5ua
12ua
CC
OS30
OS31
OC
ISp
ISpC
OSp
OSpC